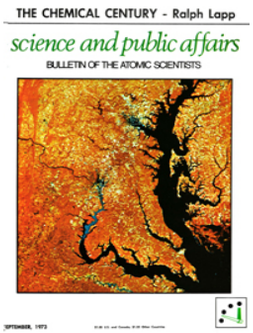

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"For the next century mankind is unlikely to run out of available energy. Instead, the important issue is whether the increasing cost of energy (including environmental costs) will become a major handicap to worldwide societal improvement." This article is based on a lecture given by Chauncey Starr, a physicist, at the Department of State in April 1973. Dr. Starr, founder of the American Nuclear Society and vice president of the National Academy of Engineering, is a member of the President's Task Force on Science Policy and served as a member of the Office of Science and Technology's Energy Panel.

Realities of the Energy Crisis

CHAUNCEY STARR

Between now and 2001, just 30 years away, the United States will consume more energy than it has in its entire history. By 2001 the annual U.S. demand for energy in all forms is expected to double, and the annual worldwide demand will probably triple. These projected increases will tax man's ability to discover, extract and refine fuels in the huge volumes necessary, to ship them safely, to find suitable locations for several hundred new electric-power stations in the United States (thousands worldwide) and to dispose of effluents and waste products with minimum harm to himself and his environment. When one considers how difficult it is at present to extract coal without jeopardizing lives or scarring the surface of the Earth, to ship oil without spillage, to find acceptable sites for power plants and to control the effluents of our present fuel-burning machines, the energy projections for 2001 indicate the need for thorough assessment of the available options and careful planning of our future course. We shall have to examine with both objectivity and humanity the necessity for the projected increase in energy demand, its relation to our quality of life, the practical options technology provides for meeting our needs and the environmental and social consequences of these options. ("Energy and Power," Scientific American, 225:3 (Sept. 1971), 37-49.)

The above quotation is taken from a paper I prepared more than two years ago. It describes the nature of the continuing problems we face—and which have recently reached public attention in the form of the energy crisis. The term "energy crisis" has served as a convenient layman's umbrella for encompassing a wide variety of society's concerns with the energy situation. Because these do not have a common solution, it is important to examine them separately and to clarify the several issues we face.

The "crisis" designation tends to be misleading, because it implies that quick-fix emergency steps should be taken to cure situations which have developed over many years. In fact, there are no quick fixes. Further, the practical realities of the situation have not yet required an immediate national "crisis" response by applying true emergency measures—such as energy rationing and cessation of energy consuming activities.

The fact that pressing localized issues have arisen should give us concern, both as indicators of widespread inadequacies and as they may portend more serious things to come. To use a medical analogy, the patient may have aches and pains, but can still do a day's work and live normally—the situation doesn't justify hospitalization now, but could get worse if remedial treatment is neglected.

In like manner, the most pressing energy need is for a coherent and long-range program to plan and manage our national and international energy systems. It takes 10 to 20 years to significantly alter the trends of these huge systems. Waiting until the situation becomes intolerable must now be recognized as intentionally planned neglect—a societal irresponsibility difficult to condone.

Our national and international energy systems consist of a complex of interlocked activities, including fuel resources (most notably the fossil fuels: coal, oil and gas), the distribution of these fuels either by pipeline, truck or tanker, the distribution of electricity generated from these fuels, and finally the many end uses of energy.

Energy is consumed for residential purposes, for transportation, by the manufacturing industry, and in sundry other ways. All activities of any energy system have some environmental impact. For example, the development of fuel resources gives rise to land use and aesthetic issues. The distribution of these fuels involves transportation risks both to the public and to our ecology.

The conversion of these fuels into either electricity or into their end functions, such as automobile transportation, industrial operations and the like, creates air polluting effluents and waste heat. In addition to these more obvious environmental impacts there are secondary by-products from energy systems that are not as directly visible to the public, but which are also important societal costs, such as fires, explosions and accidents.

The current public focus on the energy crisis

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arises primarily from a few immediately visible near-term events. First, because of the occasional shortages and malfunctions of the electricity delivery system, which cause dramatic blackouts and brownouts in spot areas, the public affected has a discomforting anxiety about the reliability of supply. The "crisis" nature of this issue tends to be very localized in place and time. The great majority of our population has no difficulty with getting electricity on demand.

The second near-term issue is that related to urban air pollution. However, air pollution arises from a great variety of sources, many of an industrial nature not directly related to the energy systems. The contribution to air pollution which arises from the generation of electricity is significant, but usually only a modest part of the total. Most notably the use of petroleum products for private and public motor vehicles is a major source. These two items, the continuous delivery of electricity and urban air pollution, are generally the stimuli for the public attention to energy issues.

Traditional Objective

The continuous delivery of electricity to meet demands, without the penalties of brownouts or blackouts or other failures, has always been the traditional objective of the electric utility industry. In order to accomplish this, the industry has anticipated a decade ahead the growth in demand for electricity, so as to schedule the construction of power generation and distribution facilities to meet such foreseen needs.

Electric utilities have also tried to maintain a sufficient surplus of generation capacity to provide a reserve for unexpected breakdowns of equipment, maintenance and other causes of disruption. In the past several years the normal anticipatory planning of the electrical industry has gone askew because of conditions not anticipated at the time when the original commitments for future plants and equipment were made. These unanticipated issues have arisen from many sources; but perhaps the two most important are, first, the recently restricted availability of suitable fuel and, second, the new environmental criteria for power plant performance.

The traditional fuel for power plants has been the fossil fuels—coal, oil and gas. Coal, while an abundant mineral in the United States, unfortunately produces the largest overall environmental impact. The mining operations, underground and strip mining, involve social costs associated with safety and land use which are quite substantial and require very large remedial investments. In addition, coal contains a large number of foreign elements, including sulfur compounds, which are environmental pollutants.

The result has been that while the demand for coal has continuously increased for power production purposes, its use creates problems which have yet to be solved satisfactorily. In particular, the ability to remove the sulfur contamination from the coal, either prior to its use or after its discharge as a gas in the power plant stacks, requires the commercial development of new technologies only now undergoing pilot plant trials.

The available indigenous oil in the United States has not been sufficient to meet our needs. Because of the slow development of both our onshore and offshore oil reserves, we have become one of the great importers of oil. Oil, like coal, contains sulfur which generally requires either removal prior to combustion or in the power plant stack gas. Naturally low sulfur oil is available in relatively small amounts.

The recent environmental restrictions on oil drilling on the continental shelf (because of the possible leakages into the marine environment), and the concern with the ecological impact of oil pipelines all have tended to slow down or inhibit the full exploration and development of oil resources.

Natural gas is the least contaminated form of fossil fuel and is, therefore, in great demand for power plant use. It is also in great demand for industrial and domestic use, because of the ease with which it can be transmitted and distributed and the simplicity of combustion equipment. For complicated reasons, including pricing policies, natural gas has been mostly a by-product of oil development. At the present time there appears to be an insufficient reserve of natural gas in the United States to permit continued expansion of its use. Thus, this most environmentally acceptable of all the fossil fuels is also the most limited for the future.

Nuclear Power

For all these reasons the utility industry recognized some years ago that the unique "clean air" characteristics of nuclear power would make it a very desirable addition to the available technical options for the generation of electricity. For almost two decades the utility industry has actively supported nuclear power development, and underwritten the higher costs of the first stages of commercializing nuclear power.

The rate at which nuclear power has entered into the production of electricity is, however, disappointingly less than that which was expected by the utilities. The initial delays were associated with establishing the reliability needed for commercial operations. More recently these plants have been delayed by the intervention of various public groups fearful of their potential environmental impact.

These interventions are primarily serving as a means of public education and communication concerning the relative safety of nuclear power. Unfortunately, the associated delays, sometimes extending for several years, have had a serious impact on reducing the planned expansion of nuclear power availability.

Thus, as a result of the combined effects of an

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"I would . . . rather accept the minimal risks of large scale nuclear power than the already evident risks of international tensions from foreign oil."

inadequate supply of environmentally suitable fossil fuels to meet expanding requirements, the time needed for technical development of anti-pollution devices to permit use of available coal and oil, and delays in the authorization for nuclear power plants, we face a near-term situation where the generating capacity of our national electricity system does not contain everywhere an adequate reserve for meeting unique peak demands and providing protection against unexpected power plant failures.

There are many regions of the country where these issues have not been pressing. Unfortunately, there are many urban areas that have had a large expansion of electricity demand, and in these the margin of reliability has been so reduced that even minor malfunctions or unusual weather conditions can create electricity shortages with considerable public discomfort and, in some cases, public hazards.

Such problems can only be avoided by administrative removal of unproductive delays and interferences, and by the most efficient use of the available resources of fuel and power generation facilities. Because it takes a decade or more to bring new technical developments or new fuel systems into operation in our energy system, it is not likely that these near-term pressures will be rapidly removed by technologies still in the process of development.

Of Basic Concern

The availability of energy has always been of basic concern because of the intimate relationship of energy to our societal development. It has become a major public issue only in the past several years, and will probably always remain with us as a primary consideration in the future. Basically our society cannot function without energy in various forms. We utilize it for elemental physical comfort by heating and cooling, we utilize it to run our industries, and we use it for recreational purposes.

All these uses have always had some impact on the environment. As our per capita use has grown in the past several generations, and as our population has grown and also concentrated in large urban areas, these environmental impacts have become sufficiently severe that we now must begin to develop either better energy technology or some limitations on energy use, or both. It must be recognized that there is no form of energy which may be used without some environmental impact.

The issue is not one of "good or bad" but one of balancing the beneficial aspects of energy use against its undesirable environmental effects. As a nation we are presently engaged in developing a socially acceptable balance between these two issues through public debate, technical and scientific research, and through empirical trial and error. This development of a sound social philosophy for the use and control of energy, so as to maximize the public good, may be one of the most important national issues of this decade.

Future Needs

Long-range planning of our national and worldwide energy systems must start with some estimate of future energy demands. A conception of the future may come from a simple extension of historical trends, or may be developed from a more sophisticated analysis of changing life styles and their impact on end-use needs.

Since 1900, the average per capita energy consumption in the world and the United States has doubled every 50 years, with some short-term perturbations. There appears to be small likelihood that this long-term trend of increasing per capita use will change in the next several decades.

In spite of increased public concern with the impacts of such a growth, there is actually very little that can be done pragmatically to limit it—other than direct scarcity or rationing—because of the intimate connection between the life styles of peoples, their aspirations and their energy supply.

The future need for energy in societal development is of two broad types, one characteristic of the highly developed sections of the world and one typical of the underdeveloped portions. During the past two centuries the industrialized nations of the world significantly increased their energy use in order to sustain their population growth and to improve the condition of their people.

It is likely that in the next century the per capita energy consumption in these advanced countries will approach an equilibrium level: first, because the quality of life for the majority of the population will be less dependent on increased energy use; and, second, because environmental constraints will make energy more costly and thus encourage increased efficiency of its end use. The hoped-for population equilibrium in advanced nations will also lead to an eventual leveling-off of total energy need for these countries.

While it is possible that the future creation of socially desirable high-technology energy consuming devices may maintain a continuously growing energy demand, nevertheless, the realities of resource economics will probably create a trade-off ceiling on energy demand. Only the development

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of new energy resources (such as fusion) which are both low cost and extensive can lift such a ceiling. Even so, the availability of investment capital—a man-made resource—may limit such growth.

For the underdeveloped part of the world, which contains most of the world's population, the situation is quite different. These peoples are still primarily engaged in maintaining a minimum level of subsistence. They have not as yet had available the power resources necessary for the transition to a literate, industrial, urban and agriculturally advanced society. Historically such transitions have always involved both an increase in population and an increase in per capita energy consumption. We are seeing this now in most of the underdeveloped countries. So, the inevitable population growth, combined with an increased per capita energy use, could result in an enormous worldwide energy demand.

A capsule example of what can occur is provided by Puerto Rico. It is being shifted to an industrial economy from an agrarian sugar economy by the planned investment of foreign capital. In 1940 the annual electricity consumption was about 100 kilowatt-hours per capita, comparable to India's present usage. By 1950 this had been more than doubled to 220 kilowatt-hours per capita. By 1968 this had increased to 1,800 kilowatt-hours per capita. This is an average doubling time of about 7 years. (By comparison, the U.S. consumption in 1968 was about 7,200 kilowatt-hours per capita with a present per capita doubling time of about 12 years. Now, in 1972, the U.S. level is about 8,800 kilowatt-hours per capita.) Puerto Rico is, of course, a unique case of accelerated economic development, but the 20-fold increase in per capita electricity consumption is nevertheless startling.

At present the United States consumes about 35 per cent of the world's energy. By the year 2000 the U.S. share will probably drop to around 25 per cent, due chiefly to the relative population increase of the rest of the world. The per capita increase in energy consumption in the United States is now about 1 per cent per year. Starting from a much lower base, the average per capita energy consumption throughout the world is increasing at a rate of 1.3 per cent per year.

It is evident that it may be another century before the world average even approaches the current U.S. level. At that time the energy gap between the United States and the underdeveloped world will still be large. With unaltered trends it would take 300 years to close the gap. By 2000 the world's average per capita energy consumption will have moved only from the present one-fifth of the U.S. average to about one-third of the present U.S. average. Of grave concern is the nearly static and very low per capita energy consumption of areas such as India, a country whose population growth largely negates its increased total production of energy.

If the underdeveloped parts of the world were conceivably able to reach by the year 2000 the standard of living of Americans today, the worldwide level of energy consumption would be roughly 10 times the present figure. Even though this is a highly unrealistic target for 30 years hence, one must assume that world energy consumption will move in that direction as rapidly as political, economic and technical factors will allow. The problems implied by this prospect are awesome.

Increasing per capita income is an essential for increasing the quality of life in underdeveloped countries, and this requires energy. It has often been suggested that because of its environmental impacts, energy use be arbitrarily limited everywhere. This requires the same type of societal decision that would be associated with arbitrarily limiting water supply or food production.

Given the objective of providing the people of the world as good a life as man's ingenuity can develop, the essential role of energy availability must be recognized. With the same motivation that causes the agronomists to seek an increased yield per acre, it is the function of technology to make energy available in sufficient amount to meet all essential needs, and with sufficiently small environmental impact as to ensure that the benefits outweigh all the costs.

Because even in the industrial societies the per capita use of energy in large amounts is only a century old, and in most of the world it has not even started, we have both a growing need and an opportunity to develop long-range plans for optimally supplying this essential aid to worldwide social development.

One can better appreciate the energy problem the world faces if one simply compares the cumulative energy demand to the year 2000—when the annual rate of energy consumption will be only three times the present rate—with estimates of the economically recoverable fossil fuels.

The estimated fossil fuel reserves are greater than the estimated cumulative demand by only a factor of two. If the only energy resource were fossil fuels, the prospect would be bleak indeed.

The outlook is completely altered, however, if one includes the energy available from nuclear power. As has often been stated, nuclear fission provides another major resource, with the present light water reactors about equal to the fossil fuels, and with the breeder reactors almost 100 times as much.

There is no question that nuclear power is a saving technical development for the energy prospects for mankind.

Promising but as yet technically unsolved is the development of a continuous supply of energy from solar sources. The enormous magnitude of the solar radiation that reaches the land surfaces of the Earth is so much greater than any of the foreseeable needs that it represents an inviting technical target.

Unfortunately, there appears to be no economically feasible concept yet available for substantially

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"The issue may be as basic as national security vs. social costs."

tapping that continuous supply of energy. This somewhat pessimistic estimate of today's ability to use solar radiation should not discourage a technological effort to harness it more effectively. If only a few per cent of the land area of the United States could be used to absorb solar radiation effectively (at, say, a little better than 10 per cent efficiency), we would meet most of our energy needs in the year 2000. Even a partial achievement of this goal could make a tremendous contribution.

The land area required for the commercially significant collection of solar radiation is so large, however, that a high capital investment must be anticipated. This, coupled with the cost of the necessary energy-conversion systems and storage facilities, makes solar power economically uninteresting today. Nevertheless, the direct conversion of solar energy is the only significant long-range alternative to nuclear power.

The possibility of obtaining power from thermonuclear fusion has not been included in the listing of energy resources because of the great uncertainty about its feasibility. The term "thermonuclear fusion," the process of the hydrogen bomb, describes the interaction of very light atomic nuclei to create highly energetic new nuclei particles and radiation. Control of the fusion process involves many scientific phenomena that are not yet understood, and its engineering feasibility has not yet been seriously studied. Depending on the process used, controlled fusion might open up not only an important added energy resource but also a virtually unlimited one. The fusion process remains a possibility with a highly uncertain outcome.

It has been proposed that tapping the heat in the rocks of the Earth's crust is feasible and, if it is, this could be important. At present, the initial probing of this source has not yet been tried, so its pragmatic availability is yet uncertain.

It is clear from all such studies that for the next century mankind is unlikely to run out of available energy. Instead, the important issue is whether the increasing cost of energy (including environmental costs) will become a major handicap to worldwide societal improvement. Just as an increasing cost of water with increasing usage might limit the development of an area, the same could apply to the use of energy in various parts of the world.

Within nature's limitations man has tremendous scope for planning energy utilization. Some of the controlling factors that enter into energy policy depend on the voluntary decisions of the individual as well as on government actions that may restrict individual freedom. The questions of feasibility, both economic and technical, depend for their solution on the priority and magnitude of the effort applied.

Basic Policy Questions

The time scale and costs for implementing decisions, or resolving issues, in all areas of energy management have both short-term and long-term consequences. There are so many variables that their arrangement into a "scenario" for the future becomes a matter of individual choice and a fascinating planning game. The intellectual complexity of the possible arrangements for the future can, however, be reduced to a limited number of basic policy questions that are more sociological than technical in nature.

The only parameters under our control which can alter the nature and trends of near-term energy systems are a limited number of individual and governmental choices—life style and value-oriented rather than technological in nature. Individual choice of an energy device (home heating, for example) can be made and implemented with a time constant of about a year. A choice by a societal unit (location of a power station or effluent regulation, for example) takes about a decade to make and implement. Thus, the full effect of such societal decisions often doesn't develop until more than a decade has passed.

In the technological domain of new economically acceptable energy devices, we are really working for the next generations rather than our own. Even nuclear power, which was certainly supported by government as enthusiastically as any technology in history, has taken 25 years to establish a commercial base—and it still hasn't made a real impact on our energy supply.

Of all the energy needs projected for the year 2000, nonelectric uses represent about two-thirds. These uses cover such major categories as transportation, space heating and industrial processes. The largest energy user at that time will be the manufacturing industry, with transportation using about half as much.

Transportation is illustrative of the possibilities in societal planning. The automobile is responsible for almost half of the world's oil consumption—and a corresponding part of its air pollution. Except for the airplane, the private automobile is the most inefficient mode of using energy for travel.

For passenger travel, railroads are 2½ times as efficient as autos and 5½ times as efficient as airplanes. Buses are 4 times as efficient as autos. For freight, railroads are 3½ times as efficient as trucks and 55 times as efficient as airplanes. Clearly, to reduce energy consumption an extensive nationwide network of railroads, with local bus service, is far superior to an automobile road network. Unfortunately, the worldwide trends have been diametrically opposite, and the human preference for personal mobility has reinforced such trends.

Finally, contrary to much public comment, the development of new speculative energy resources

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are investments for the future, not a means of remedying the problems of today. Unfortunately, many of these as yet uncertain and undeveloped sources of energy are often misleadingly cited publicly as having a great promise for solving our present difficulties. In addition to their technical uncertainties, many of these speculative sources are likely to be limited in their contribution, even if successful.

Unfortunately, the attraction of "jam tomorrow" may persuade us to neglect the need for "bread and butter" today. Because of the very long time required for any new energy device to become part of the technological structure of our society, these speculative sources could not play a major role before the year 2000. The quality of life of the peoples of the world depends upon the availability in the near future of large amounts of low cost energy in useful form. This being the case, we must plan an orderly development and efficient use of the resources available to us now, and these are primarily fossil fuels and nuclear fission.

Given this situation, what are the possible impacts on U.S. relations with foreign countries. Because of our present limitations on the use of high sulfur coal, and the present unavailability of more natural gas, a rapid shift to oil is now under way, because oil can be found with low sulfur or can be desulfurized.

There is no emergency remedy except rationing. Because roughly half our oil goes to transportation, this is the likely area to be controlled, not electricity. U.S. oil production can be increased only fractionally, even if all internal controls are removed.

Foreign Oil

If the politically distasteful course of rationing is not taken, our 1970 foreign oil purchase of $5 billion will become $10 billion in 1975, and $15 billion by 1980, at which time half our oil consumed will be foreign. For perspective, these dollar outflows may be compared with the total U.S. annual capital investments of less than $100 billion. I will not dwell on the international monetary consequences.

It should also be remembered that increased fuel cost means increased cost of goods, reduced foreign sales and worsened trade balance. The foreign relations issue is, of course, aggravated by the increasing dependency of the United States on the oil producing nations without a balancing dependency on their part. The international tensions so produced can lead to consequences of the most serious nature, a variety of scenarios can be imagined.

A parallel situation exists in Western Europe, and both France and Germany have embarked on the construction of oil storage facilities to provide at least three months reserve. (The United States now has a 2 to 3 week stored supply.) The recent North Sea discoveries will help, but not solve this problem. These countries are also developing pipeline connections to the USSR and Eastern European oil fields. Western Europe and the United States may end up in conflict for limited world resources.

For the United States, the Canadian supplies are attractive, but both trade barriers and lack of incentives have made this a slowly developing course. Perhaps we should offer them deuterium oxide (heavy water) for their oil. The Canadians have no reason to be concerned with our problem and may be viewing it with some skepticism, as do many foreigners.

After all, the environmental issues that have engendered our situation have a very dubious rationality. The public health causality relations which are the reputed origin of our pollution standards are not, in fact, based on demonstrable or credible risk-benefit analyses. They are instead judgmental levels set primarily for aesthetic or comfort purposes, with health benefit marginal at best. This is not likely to create international sympathy.

No Quick Fix

Although the near-term U.S. situation has no quick fix, the intermediate term (post-1980) has several optional aids. Offshore drilling, for example. This is much less polluting than tanker imports, and given time could probably meet much of our needs. Of course, we must resolve the issue of the "law of the sea" if we wish to exploit the resources beyond the three-mile limit. Another option is to ease the environmental and aesthetic constraints and reactivate coal mining, and this may occur when the public realizes the situation. Another is speed up coal desulfurization, gasification and liquefaction, and the recovery from oil shales and tar sands. These take both the development of commercial technology and much capital.

In the very long term (post-2000) we have the "clean air" option of nuclear power. The abundance of uranium and the fast breeder gives us potentially ample energy. Obviously, the rate at which nuclear power comes on the scene is dependent in the United States on public acceptance. It should be pointed out that this issue does not exist in most foreign countries. As a consequence, we may be buying foreign reactors eventually.

We must recognize and resolve the several very basic trade offs between environment, life styles, personal freedoms, amenities, international tensions, high energy cost and high cost of goods, public health, personal income, allocation of national resources, and perhaps others. The issue may be as basic as national security vs. social costs.

For example, based on my perceptions of the alternatives, I would very much rather accept the minimal risks of large scale nuclear power than the already-evident risks of international tensions from foreign oil. These issues are so important, and the energy systems so ponderous and slow to change, that our national planning must be based on comprehensively developed long-range insight rather than on fickle public emotion and short-term political expediency. Let us hope it is.

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